SURGICAL ASPECTS, FINITE ELEMENT ANALYSIS AND X-RAY CORRELATION OF FEMORAL NECK CHANGES IN THE OSTEOARTHRITIC HIP AFTER HIP RESURFACING SURGERY

THIS IS A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE

DEGREE OF DOCTOR OF PHILOSOPHY

BY

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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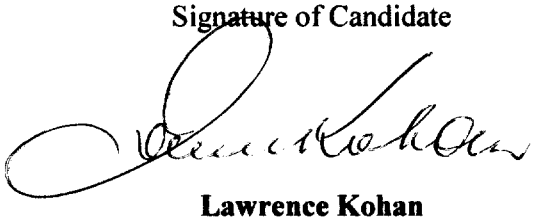

Lawrence Kohan

To my parents.

"The more sand has escaped from the hourglass of our life, the clearer we should see through it."

Niccolo Machiavelli (1469–1527) Florentine philosopher, writer and one of the founders of modern political science

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My gratitude to you all.

ABSTRACT

Background:

Hip resurfacing is a logical choice for the treatment of symptomatic osteoarthritis as the degenerative process affects primarily the articular surface. It has been tried previously but failed. Recent improvements in metallurgy, manufacture and engineering have resulted in the development of a new series of implants which appear to be much more successful. Over the last 10 years, they have been used with enthusiasm and increasing popularity. However, over the last two years or so, their popularity has diminished with an awareness of significant complications developing. The complications relate primarily to early fracture, and the possible development of adverse reactions to metal ions. Component position may be implicated in the development of these complications.

Aims:

1. To examine x-rays post-operatively of patients who have had hip resurfacing surgery and determine whether bone remodelling has occurred

2. If it has occurred, whether it is consistent with the changes predicted by the loading redistribution by the finite element stress analysis.

3. The use of finite element analysis to measure the effects of surgical technique and some of the factors related to femoral component positions on the bone stress distribution and morphological changes over time.

4. Improvements and suggestions regarding surgical aspects, (alterations in the valgus and varus alignment, the effect of anti-version and retro-version of the femoral component, the effect of incomplete seating of the femoral component and the effect of the cement mantle thickness) and to address concerns in relation to hip resurfacing surgery.

Materials and Methods:

For the x-ray analysis 89 patients with 90 resurfacings were present in our database. The Birmingham (Smith and Nephew) hip resurfacing was used in all patients. There were 68 men and 22 women, with a mean age of 52 years. All patients had the underlying diagnosis of osteoarthritis. 33 patients agreed to be part of the study and were available for evaluation. These patients had x-rays, which were accurate enough to determine the measurements. Standardized AP x-rays were obtained so that the femoral neck could be measured in a reproducible way.

For the finite element analysis, a three-dimensional mesh was created using ten node tetrahedral elements. The bone contours on which the mesh was based on were extracted from CT scans. The material properties derived from the CT scans were applied locally. Muscle forces were applied as at heel strike, during normal gait. Two models were created, a reference or preoperative model and a treated, post-operative model. The integration points served as sensors. Both models were loaded identically over a period of 48 virtual months and the changes between the reference and the treated models assessed. Bone mass gain or loss was assessed as

well as the region of the femoral head and neck where the change occurred, determined. The effect of alterations in the valgus and varus alignment, the effect of anti-version and retro-version of the femoral component, the effect of incomplete seating of the femoral component and the effect of the cement mantle thickness were variables which were examined.

Results:

Alterations in bone mineral density developed quickly after implantation and appeared to be stabilised within 12 months. Under the femoral component superiorly, bone loss occurs. In other areas, generally, an increase in bone density is seen. Maximum bone loss under the femoral head was approximately 85%, and maximum bone in gain at the base of the femoral neck inferiorly was 60%. The optimal valgus alignment was close to neutral in the femoral neck and highly valgus and varus alignments led to the development of bone loss. In relation to the version of the femoral stem within the neck, slight anteversion, 5°, as opposed to retroversion was favourable. Incomplete femoral component seating lead to significant alterations in tensile strain and potential displacement. Both displacement and strain rose dramatically beyond 3 mm of incomplete seating. The cement mantle thickness modelling was inconclusive as to its effect but it was noted that the most dramatic bone mass loss was with the cementless implant.

In the x-ray analysis we found that immediately under the femoral component, the femoral neck diameter diminished by 3.52% ($p=0.001$). Distally, the neck

increased in diameter by 3.13% (p =0.011). On the control side, no significant change in the neck width was observed.

An increase in the body mass index produced increasing widening at the base of the femoral neck but the neck narrowing under the femoral component was not affected by BMI.

We did not see an influence of age on the changes in femoral neck width in the resurfacing patients.

Conclusion:

There is change in the femoral neck morphology after hip resurfacing surgery. Finite element analysis has predicted that this would occur as a result of changed loading patterns. The location and type of remodelling that has occurred, was also predicted by the finite element analysis. The change in neck width appears to be a manifestation of remodelling of bone in response to these altered loading patterns.

It was clearly established that surgical techniques such as a slightly valgus component alignment, with a neutral or slightly anteverted stem, induced changes. Remodelling was seen on follow-up x-rays. A cemented and fully seated femoral component is the optimal alignment. In the proximal part, stress shielding occurs, while distally, where the stress shielding was less, the effect of body weight on the remodelling was more pronounced.

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ABBREVIATIONS

CT – Computer Tomography

MRI – Magnetic Resonance Imaging

FEA – Finite Element Analysis

CNC – Computer Numerically Controlled

CAD – Computer Aided Design

CAM – Computer Aided Manufacturing

DICOM - The Digital Imaging and Communications in Medicine

BHR – Birmingham Hip Resurfacing

C of G – Centre of gravity

DEXA – Dual-energy Xray Absorbtiometry

VHD – Visual Human Data

HU – Hounsfield Unit

BMD – Bone Mineral Density

ROI – Region of Interest

BMI – Body Mass Index

LIST OF PUBLICATIONS

GILLIES, R. M., HOGG, M. C., KOHAN, L. & CORDINGLEY, R. L. 2007. Adaptive bone remodelling of all polyethylene unicompartmental tibial bearings. *ANZ J Surg,* 77, 69-72.

GILLIES, R. M., KOHAN, L. & CORDINGLEY, R. 2007. Periprosthetic bone remodelling of a collum femoris preserving cementless titanium femoral hip replacement. *Comput Methods Biomech Biomed Engin,* 10, 97-102.

NIZAM, I., KOHAN, L. & KERR, D. 2007. Nocardia nova septic arthritis following total knee replacement: a case report. *J Orthop Surg (Hong Kong),* 15, 390-2.

KERR, D. R. & KOHAN, L. 2008. Local infiltration analgesia: a technique for the control of acute postoperative pain following knee and hip surgery: a case study of 325 patients. *Acta Orthop,* 79, 174-83.

KERR, D. & KOHAN, L. 2009. Anaesthesia with Special Emphasis on Pain Control. *In:* MCMINN, D. (ed.) *Modern Hip Resurfacing.* London: Springer.

KERR, D. & KOHAN, L. 2009. Recovery and Rehabilitation. *In:* MCMINN, D. (ed.) *Modern Hip Resurfacing.* London: Springer.

NIZAM, I., KOHAN, L. & KERR, D. 2009. Hip resurfacing in an 88-year-old patient? Highlighting selection criteria for hip resurfacings in patients older than 65 years. *J Arthroplasty,* 24, 1143-1147.

CORDINGLEY, R., KOHAN, L. & BEN-NISSAN, B. 2010. What happens to femoral neck bone mineral density after hip resurfacing surgery? *Journal of Joint and Bone Surgery (UK),* (in print).

CHOU, J., BEN-NISSAN, B., GREEN, D.W., VALENZUELA, S. M. & KOHAN L. 2010. Targeting and dissolution characteristics of bone forming and antibacterial drugs by harnessing the structure of micro-spherical shells from coral beach sand, *Adv. Eng. Mater.,* (in print).

CONFERENCE PROCEEDINGS

2007 Orthopaedic Research Society, Annual Meeting, San Diego, USA, February 2007 Adaptive bone remodelling of the Birmingham of hip resurfacing and Cormet Components – Poster. Impaction loads during insertion of hip resurfacing components – poster. Birmingham hip resurfacing implant surgical orientation influence on adaptive bone remodelling – Poster

2007 Institution of Mechanical Engineers, Engineers and Surgeons: Joined at the hip conference, London, England, April 2007 Monte Carlo Simulation of Biomechanics and Fracture Risk in Hip Resurfacing

2007 Australian Orthopaedic Association Annual Scientific Meeting, Gold Coast, Australia, October 2007 Birmingham Hip resurfacing in the over 65 age group – a case series of 114 patients. Impaction loads during the insertion of hip resurfacing components. What happens to femoral neck bone mineral density after hip resurfacing surgery?

2007 The Medlaw & AOA Medico Legal Society Clinical Conference, Sydney November 30 – December 2, 2007 Hip Resurfacing – an update

2008 Orthopaedic Research Society 54th annual meeting, San Francisco, March 2-5 "The influence of femoral hip resurfacing internal geometry on the loading of underlying bone – a finite element study." Gillies R.M., Kohan L., Hogg M., Appleyard R.C. "Impaction loads during insertion of hip resurfacing implant: a finite element study" Hogg M. C., Kohan L., Appleyard R., Gillies R. M. "The effect of hip resurfacing acetabular version angle on ion level changes – a finite element study"

2008 European Orthopaedic Research Society, 17th Annual Meeting, Madrid, April 25 – 26 "Hip resurfacings in patients over 65 years of age? A single surgeon cases series of 111 Birmingham hip resurfacings in 105 patients" Nizam I., Kohan L., Kerr D.. "A case series of ninety nine hybrid metal-on-metal hips- Birmingham resurfacing cup and Birmingham modular head" Nizam I., Kohan L., Kerr D. "Do non-steroidal anti-inflammatory drugs cause endoprosthetic loosening?" Nizam I., Kohan L., Kerr D.

2008 Australian Orthopaedic Association Annual Scientific Meeting, Hobart, October 12 -16 "Laser guided component implantation" Kerr D., Kohan L. "Finite element analysis and surgical considerations of the impact of osteoporosis and osteoarthritis on hip resurfacing." Kohan L., Brown T. "Metal on metal hip arthroplasty – Birmingham resurfacing cup and Birmingham modular head - a single surgeon series of 99 hip arthroplasties." (Poster) Nizam I., Kohan L., Kerr D. "Do non-steroidal anti-inflammatory drugs cause endoprosthetic loosening?" (Poster) Nizam I., Kohan L., Kerr D.

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